NAFEC Major Accomplishments in the Study of the Toxicity of Burning Cabin Materials from July 26, 1974, to January 28, 1975, and Recommendations to Support Regulatory Proposals.

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As presented by C. Sarkos in Washington, D. C. on January 28, 1975

Gentlemen. Thank you for finding the time to permit me to summarize recent NAFEC efforts, since our last meeting 6 months ago, toward developing a toxic gas emission criteria for burning cabin materials. I can imagine that much of your time is being spent reacting to the adverse criticisms by both ABC's Jules Bergman and a congressional study of FAA's role in aviation safety. A greater and more frequent exchange of technical information, as I hope will transpire today, will better equip FAA to fulfill its responsibility of making air travel as safe as is technically and economically possible.

First viewgraph please. The general outline of my presentation is divided into four parts: major accomplishments, major conclusions, present efforts, and recommendations. I would like to preview the presentation by stating that for the first time we have some preliminary evidence that supports the contention that a toxic gas emissions regulation can be based on an analytical approach. This evidence is the result of recent tests conducted at CAMI at the informal request of Dr. Joe Spurgeon of NAFEC wherein animals were directly exposed to the combustion products of a small number of interior materials previously analyzed at NAFEC. First, however, I would like to chronologically describe our major accomplishments over the last 6 months.

Next viewgraph please. Much of the work that we have done was with 15 cabin materials, used in wide-bodied jets, selected because of their known chemical or physical makeup or wide usage. We tested five fabrics - 100 percent PVC, 100 percent wool, two PVC/wool blends of different known proportions, and Nomex, a popular fire resistant fiber developed by DuPont. Two identical wool pile carpets were tested, except No. 34 also had a urethane pad backing. In order to evaluate the performance of fabricated assemblies, we tested three panels - No. 24 consisted of a PVC core with fiberglas faces, No. 56 was a Nomex honeycomb panel with aluminum faces and a PVC finish, and No. 67 was a Nomex honeycomb panel with fiberglas faces and a PVC finish. Finally, we analyzed five seat foams, which are especially hazardous because of their cellular construction - No. 86 was a PVC foam, while the remaining were urethanes, Nos. 79 and 143a were polyether types and Nos. 104 and 143c were polyester types. Gas analysis was limited to the known predominant toxic species for these materials - CO, HCN, AND HCl.

Next viewgraph please. I have selected four major accomplishments for discussion. These are based on analysis of the previously shown materials and gases and are described in an FAA interim report prepared by Joe Spurgeon which has thus far undergone initial review and appropriate revision. Let's just look at the first major accomplishment - we have "compared different methods of sampling and analyzing combustion gas mixtures from the NBS chamber in order to best determine gas concentration-time profiles."

Next viewgraph please. We compared four methods of sampling combustion gas mixtures from the NBS chamber - direct colorimetric tube, Saran bags, fritted impingers or bubblers, and syringes. Without getting into the details of the comparison or a description of the NBS chamber with which most of you are familiar, I would just like to say that syringe sampling was by far the best method. It has the following advantages: (1) "Best sample recovery of the methods evaluated" - i.e., gas losses from the sampling technique were minimal; (2) "Rapid sampling time (approximately 10 seconds)" - thus, the sample is almost representative of that at a particular point of time during the test rather than the average over some sampling interval; (3) "small sampling volume (30 cc = 0.006 percent of the NBS chamber volume)" - we do not have to be concerned over dilution of the gas mixture as a result of a large sample volume; (4) "chemical resistant Teflon plunger and hub" - this helps to assure high sample recoveries; (5) "simultaneous multiple syringe sampling is practical" - thus, at the same time, we can sample a number of gases that may each require a different absorbing solution; and (6) "simple manual operation" - thus, if necessary, we could utilize untrained personnel to take samples during a test.

Next viewgraph please. This viewgraph depicts the smoke and toxic gas levels of a vinyl fabric tested in the NBS chamber and typifies the type of data that is forthcoming on 75 wide-bodied cabin materials. HCl was measured at 1-minute intervals from syringe samples. A dangerous peak concentration of 2750 ppm was measured. Carbon monoxide, as measured with an infrared gas analyzer, increased progressively for the entire 10-minute test in an approximately linear fashion (CO has behaved in this manner for all materials tested thus far in the NBS chamber). The smoke level as measured with a photometer reached a maximum specific optical density of 200 at 3 minutes. Compared to other reasonably priced and readily available materials, in terms of a smoke and especially toxic gas hazard, as you will find later in the presentation, this fabric has no place in a commercial transport cabin.

May I have the third viewgraph again? Our second major accomplishment was as follows: we "compared the NBS smoke chamber and combustion tube furnace with regard to the credibility and reproducibility of combustion gas measurements."

Next viewgraph please. Let's examine the procedure used for testing a material in the combustion tube furnace. A test sample, usually weighing about 10 mg, is placed in a high-temperature glass tube. Air is drawn through the glass tube by a vacuum pump and the flow rate measured with a rotometer. The test begins when the tube with sample is inserted into an annular furnace preheated to a prescribed, fixed temperature - usually $600^{o}C$, or about $1100^{o}F$. Over the 10-minute test duration, the effluent composed of the combustion products and carrier air stream is passed through a fritted bubbler containing an absorbing solution. After the test the ion concentration in solution of the specific gases of interest is measured with the appropriate ion selective electrodes. Thus, and this is important, the total quantity of toxic gases produced by the burned specimen is collected and measured in the bubbler. In contrast, in the NBS smoke chamber, gas measurements are performed at a selected location in the chamber and at specified, periodic times during the test. The absence of the independent variables time and space in the combustion tube test procedure assure a high accountability of the quantities of toxic combustion gases.

Next viewgraph please. For the selected 15 materials, the reproducibility of HCl, HCN, and CO measurements was compared between the NBS chamber and combustion tube furnace. This viewgraph shows the comparison of HCl produced by testing a 100 percent PVC fabric. Three replicate tests were conducted for each test method. The maximum concentration of HCl measured in the NBS chamber was converted to the yield of HCl per weight of specimen which in turn was related to the percentage of theoretical yield, i.e., the ratio of the amount of HCl measured in the combustion gas mixture to the amount of HCl known to exist in the unburned polymer. For this material and gas, the relative standard deviation is excellent for both test methods, but is slightly higher for the NBS chamber. Notice, however, that the average percentage theoretical yield is close to 100 percent for the combustion tube furnace, which is also about 23 percent higher than for the NBS chamber.

Next viewgraph please. The generally higher and more credible recovery of combustion gases in the tube furnace compared to the NBS chamber is illustrated on this viewgraph. The yield of HCN measured per weight of material is plotted as a function of wool content for both test methods. Three wool/PVC blended fabrics containing 49 percent, 76 percent, and 100 percent wool were tested. For the combustion tube furnace - circular data points - the linearity of the plot indicates that the production of HCN was predictable, and also that the yields may have been quantitative. In contrast, the recovery of HCN in the NBS chamber was significantly lower and did not follow a rational behavior.

May I have the third viewgraph again. Our third major accomplishment was as follows: we "ranked materials on the basis of a relative hazard index calculated from toxic gas measurements in the NBS smoke chamber and combustion tube furnace."

Next viewgraph please. The task of analytically evaluating the toxicity of a wide spectrum of polymeric materials, including fabrics, films, transparencies, foams, laminates, and assemblies, each of which can produce large quantities of different gases from one another, is indeed formidable. The simplest approach to solving this problem is to calculate a relative hazard index, or RHI, for each material. We have used an equation similar to the one proposed by Sumi and Tsuchiya. It is assumed that the toxicity of a material due to a specific combustion gas is a linear function of the concentration of that gas (Ce) relative to the tolerance limit (Ci). Also, the contribution of different gases are assumed to be additive. For the three gases measured in this study we have estimated 5-minute tolerance limits from various literature sources. I must emphasize that experimental data are lacking in this area. A sample calculation of RHI is shown. Suppose the concentration of CO is 600 ppm, HCN is 600 ppm and HCl is 5 ppm. The RHI is calculated to be 3.22. We also see that HCN was by far the predominant toxic species, and that the contributions of CO and HCl to the toxicity were about equal although much less than HCN.

Next viewgraph please. One objective of this study was to compare the relative hazard indices calculated from analytical data from the combustion tube and the NBS chamber. On this viewgraph, we have ranked materials from four classes - fabrics, foams, carpets, and panels - on the basis of decreasing toxicity from combustion tube data, and compared this ranking with that predicted from NBS chamber data. I should emphasize that a comparison of the absolute values of RHI for the combustion tube and NBS chamber has no significance since the combustion tube rating is on a unit weight basis while the NBS chamber rating is per unit area. Furthermore, the combustion tube data consists of the total amount of toxic gas produced that was diffused into the 2-liter volume of the carrier gas, whereas the NBS chamber data consists of the peak concentration, in time, inside the 510-liter chamber volume. First, note that the fabrics are ranked in the same order by both methods, with the PVC being the most hazardous. This was the only class in which the relative ranking by both methods was identical. Although three of the foams were ranked in the same order, materials 79 and 104 were reversed. For the two carpets, the combustion tube data rated the wool pile with urethane backing to be more hazardous than the unbacked carpet, whereas in the NBS chamber both carpets were rated equally. Similar discrepencies existed for the panels, although both methods judged panel 24 to be least hazardous. The general agreement between the two test methods in ranking for the fabrics and foams and lack of agreement for the carpets and panels is understandable. Differences in methods of specimen exposure to heat between the combustion tube and NBS chamber should not effect the burning of the uniform fabrics and foams as much as the layered carpets and panels.

Next viewgraph please. On this viewgraph we have the general ranking of the 15 materials analyzed based on a calculated relative hazard index from combustion tube data and from NBS chamber data. Some very important trends are evident. Both tests methods rated the PVC-containing materials to be the seven most hazardous. These included panels, foams, and pure and blended PVC fabrics. In part, this high hazard is related to the relatively low brief exposure limit of 50 ppm estimated for HCl. The next three most hazardous materials agreed upon by both test methods were the wools, including two carpets and a seat fabric. After this the agreement ends. From the combustion tube data, Nomex was rated more hazardous than the urethane foams, while just the opposite was predicted using NBS chamber data. At this point we asked ourselves a very obvious but nevertheless important question: were the above rankings or trends plausible? The most direct way to answer this question was to conduct animal tests with the same materials that we analyzed.

May I have the third viewgraph again? Our fourth major accomplishment was that we "participated in tests at CAMI consisting of the exposure of rats to the combustion products from selected materials and correlated the animal behavior with gas measurements performed at NAFEC." Joe Spurgeon contacted Drs. Paul Smith and Charles Crane at CAMI and they expressed an interest in and willingness to conduct preliminary animal studies on a small number of materials. A test apparatus was assembled in several weeks and Joe flew down to CAMI to participate in the experiments.

Next viewgraph please. A schematic drawing of the animal test apparatus is shown on this viewgraph. Two rats were placed in a 5.6-liter exposure chamber. A fan was provided to mix the combustion gases. The material - nominally 500 mg - was burned in a combustion tube furnace at approximately 600°C. Two tests were conducted per material. The first visible smoke entered the chamber about 2 minutes after the test was initiated. Passage of the combustion gases into the chamber was also aided by injections of air from the closed end of the tube furnace at 3, 5, and 10 minutes by a 100-cc syringe. The material was burned for 10 minutes and the animals remained in the exposure chamber for 30 minutes. Nine of the 15 materials analyzed at NAFEC were also tested at CAMI. These tests were completed in only 3 days. The nine materials selected were: five fabrics, including PVC, wool, two PVC/wool blends with different proportions, and Nomex; two carpets, one with a wool pile only and the other a wool pile and urethane pad backing; and two urethanes, a polyether and a polyester.

Next viewgraph please. This viewgraph shows a plot of the time to incapacitate the rats (y axis) vs the yield of HCN from the combustion tube as measured at NAFEC. The relative toxicity of the materials is being compared by using the times to incapacitation rather than the time to death, since the former measurement is more relevant to escape from a cabin fire. Moreover, time to incapacitation is a more reproducible measurement, as shown by the lines through the data points which indicate plus and minue the standard deviation. Although the results from this series of tests are preliminary in nature, they suggest that the time of incapacitation may be related to the HCN yields from previous combustion tube experiments. This does not mean that the incapacitation of an animal necessarily resulted from the HCN concentration in the exposure chamber. Rather, this apparent correlation suggests that the analysis of combustion gases for HCN may provide an indication of animal toxicity for many nitrogen-containing materials. Nomex and a wool (76 percent)/PVC (24 percent) blend were the only materials that did not lie on the curve fit. The toxicity of Nomex is less than that predicted from the total yield of HCN alone, as measured from the combustion tube furnace. One possible explanation for this behavior can be found upon examination of the HCN concentration-time curve for this material tested in the NBS chamber. This curve exhibits a sharp upturn after 7 - 10 minutes. Thus, the benefit of Nomex is by way of its thermal stability and resulting protracted period of decomposition. However, once decomposition of Nomex has occurred, the resulting products appear to be highly toxic. The example of Nomex illustrates a major deficiency in the combustion tube data - the absence of any indication of the rate of toxic gas generation - and underlies our reluctance to abandon the NBS chamber for the more accountable and reproducible combustion tube furnace. The relatively high toxicity of material 82, a 76 percent wool/ 24 percent PVC blend, cannot be explained analytically, although it is possible that reduced concentrations of HCl act as a synergist to the combustion products of nitrogen-containing materials. The 100 percent PVC fabric is not included on the plot since it is not a nitrogen-containing material. However, the average time to incapacitation for this material was only 3.5 minutes. Therefore, the animal test results for homogeneous materials indicate that PVC is more toxic than wool which is more toxic than Nomex which is more toxic than urethane; this ranking was also predicted by the relative hazard index calculations using combustion tube data. The greater toxicity of polyether urethane (79) compared to the polyester type (104) and the wool pile carpet with urethane pad (34) compared to the unbacked carpet was also predicted correctly from combustion tube data.

Next viewgraph please. I would now like to briefly list the major conclusions reached at this time. One, "syring..... evaluated." The other methods evaluated were direct colorimetric tubes, Saran bag sampling and fritted impingers. Two, "Reproducibility of..... methodology." Materials which have exhibited variability in the NBS chamber have been the thermoplastics and urethane foams. Three, "In the..... HCl." Undoubtedly, the high accountability of gases in the combustion tube is related to the fact that the entire effluent over the test duration is measured. Four, "The ranking .... panels." Five, "A computed..... or Nomex." This order was predicted based on data from the combustion tube or NBS chamber; however, the combustion tube ranked Nomex more toxic than urethane, and the NBS chamber vice versa. Six, "The.... data." Seven, "Preliminary ..... furnace." I must emphasize here that <u>at this time</u> we are only saying that HCN was a good indicator of the toxicity of the material. Eight, "Some ...... burned." Specifically, I am referring to the extremely toxic behavior of the 76 percent wool/24 percent PVC blended fabric that incapacitated the animals in 2.7 minutes. Nine, "Determination..... gases." We feel that animal studies could be completed in a reasonable period of time on the 75 materials being analyzed at NAFEC. Ten, "A preliminary....... approach." This was an important finding that was assumed to be valid in the 9550.

Next viewgraph please. Here we have typical data obtained recently with colorimetric tubes on a wool pile carpet with urethane pad backing tested in the NBS chamber. Gases detected were CO, HCl, HCN, NOX, aldehydes, and SO_2. Since HF, H_2S, and NH_3 were not detected, analysis for these gases will be excluded when this material is retested using accurate analytical methods. This carpet was very smokey, producing a maximum specific optical density of 431, significantly higher than the proposed limit of 200.

Next viewgraph please. The final part of my presentation is concerned with recommendations to satisfy Flight Standards Service regulatory proposals on toxic gas emissions and cabin fire safety in general. Recommendations concerning toxic gas emissions proposals are divided into 2 parts: first, minimal additional efforts required to support a near-term NPRM, and second, comprehensive efforts required to support a far-term NPRM.

Next viewgraph please. A question often raised is: what is the minimal efforts required to support a toxic gas regulation? The concensus of workers in the field of combustion gas technology is that some form of animal testing is required, although the extent is often debated. At NAFEC we feel that a regulation limiting toxic combustion gas levels based on analytical data unsubstantiated by animal toxicity studies would be severely criticized by the airframe manufacturers, material suppliers, NASA, NBS, the academic community, etc. Therefore, we are recommending that at the very least "CAMI be requested to conduct tests with animals exposed to the combustion products of the 75 cabin materials presently being analyzed at NAFEC." Because of the success and important findings of the preliminary study, we know that CAMI is very interested in continuing this work, even on a large number of materials as we propose. We are encouraged by the correlation of animal responsiveness determined by tests at CAMI with analytical measurements conducted at NAFEC, and are cautiously anticipating similar relationships for most of the remaining materials. Most people we have talked with would like to see a regulation based on analytical toxic gas limits with proven physiological significance. Therefore, it is important that "this effort be coordinated with NAFEC to assure a consistent approach and common goals." Finally, we feel that this effort at CAMI should include the following: -"measurement..... monitoring."

Next viewgraph please. I have also constructed the basic logic for a comprehensive program to support a toxic gas emissions regulation. The components of this program beyond the minimal needs are enclosed in the dashed block. In either case, the initial effort consists of two tasks: direct animal exposures to the combustion products from interior materials and analytical measurements of these combustion gases. If the animal responses can be correlated from the analytical data, then full-scale tests, for example, to measure the safety provided by limiting materials combustion gas levels, and the relationship of animal to human behavior, are necessary before deriving a defendable regulation. Note that both of these tasks have possible feedbacks to the initial efforts. On the other hand, if the initial animal/analytical data cannot be correlated because of synergistic, antagonistic, or unknown effects, then it may be necessary to perform acute single or multiple synthetic gas exposures to determine animal responsiveness, or complete quantitative and qualitative analysis of the combustion gas mixture.

Final viewgraph please. Many questions concerning cabin fire safety can only be answered by conducting full-scale tests. Until this time full-scale tests have been conducted primarily in perishable, surplus aircraft and have either been "one-shot affairs" or have required extremely long setup times for a test. A permanent, full-scale, wide-bodied cabin fire test facility is in the preliminary planning phase and is an integral part of future NAFEC work related to cabin fire safety. This facility would be applied to support regulatory needs in this safety area. For example, it would enable you to "determine the.....etc.)"

This concludes my presentation. If there is one message that I would like to leave with you, it is that animal testing is an integral part of any toxic gas emissions regulation, and that immediate efforts should be made to utilize CAMI's recognized expertise in this area in a coordinated effort with NAFEC.

ACTIVITY 181-521-010: DEVELOP A TOXIC GAS EMISSION CRITERIA FOR INTERIOR MATERIALS

GENERAL OUTLINE OF PRESENTATION

1. MAJOR ACCOMPLISHMENTS
2. MAJOR CONCLUSIONS
3. PRESENT EFFORTS
4. RECOMMENDATIONS

COMPOSITION OF THE MATERIALS USED IN THIS STUDY

MATERIAL NUMBER	MATERIAL CATEGORY	MATERIAL COMPOSITION	GASES MEASURED
81	FABRIC	POLYVINYLCHLORIDE	CO, HCl
96	FABRIC	WOOL (49 PERCENT) /PVC (51 PERCENT)	CO, HCl, HCN
82	FABRIC	WOOL (76 PERCENT)/PVC (24 PERCENT)	CO, HCl, HCN
88	FABRIC	WOOL	CO, HCN
78	FABRIC	NOMEX	CO, HCN
33	CARPET	WOOL PILE/POLYESTER BACKING/ LATEX COATING	CO, HCN
34	CARPET	WOOL PILE/POLYESTER BACKING/ LATEX COATING/ URETHANE PAD/NYLON SCRIM	CO, HCN
24	PANEL	EPOXY-FIBERGLAS/PVC CORE/EPOXY-FIBERGLAS	CO, HCl
56	PANEL	PVC/ALUMINUM/NOMEX HONEYCOMB/ALUMINUM	CO, HCl
67	PANEL	PVC/PHENOLIC-FIBERGLAS/NOMEX HONEYCOMB/ EPOXY-FIBERGLAS	
79	FOAM	POLYETHER URETHANE	CO, HCN
104	FOAM	POLYESTER URETHANE	CO, HCN
143a	FOAM	POLYETHER URETHANE	CO, HCN
143c	FOAM	POLYESTER URETHANE	CO, HCN
86	FOAM	POLYVINYLCHLORIDE	CO, HCl

MAJOR ACCOMPLISHMENTS*

FOR A SMALL NUMBER OF SELECTED CABIN MATERIALS AND COMBUSTION GASES, WE HAVE:

(1) COMPARED DIFFERENT METHODS OF SAMPLING AND ANALYZING COMBUSTION GAS MIXTURES FROM THE NBS SMOKE CHAMBER IN ORDER TO BEST DETERMINE GAS CONCENTRATION-TIME PROFILES.

(2) COMPARED THE NBS SMOKE CHAMBER AND COMBUSTION TUBE FURNACE WITH REGARD TO THE CREDIBILITY AND REPRODUCIBILITY OF COMBUSTION GAS MEASUREMENTS.

(3) RANKED MATERIALS ON THE BASIS OF RELATIVE HAZARD INDEX CALCULATED FROM TOXIC GAS MEASUREMENTS IN THE NBS SMOKE CHAMBER AND COMBUSTION TUBE FURNACE.

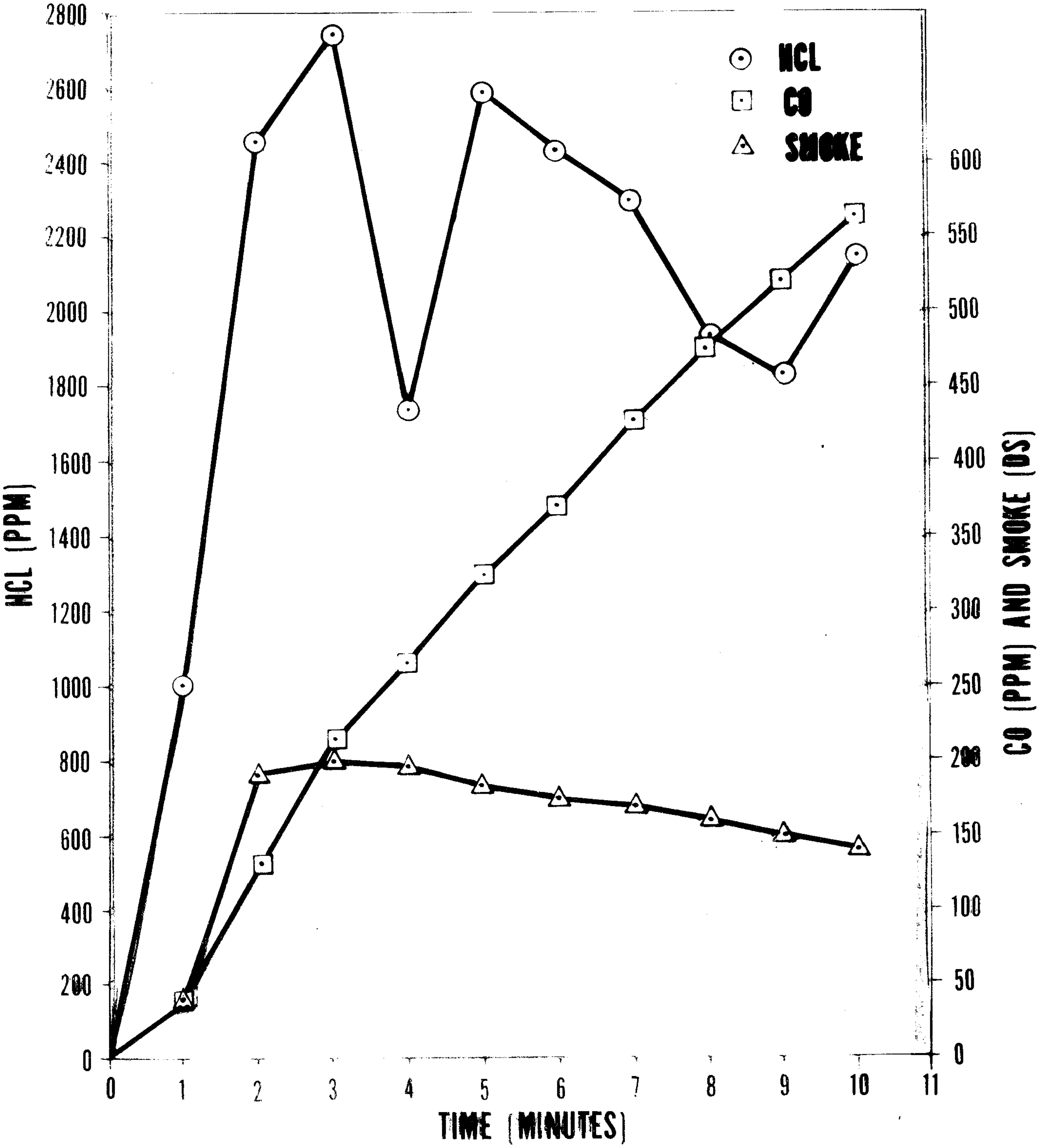
(4) PARTICIPATED IN TESTS AT CAMI CONSISTING OF THE EXPOSURE OF RATS TO THE COMBUSTION PRODUCTS FROM SELECTED MATERIALS AND CORRELATED THE ANIMAL BEHAVIOR WITH GAS MEASUREMENTS PERFORMED AT NAFEC.

*AN FAA INTERIM REPORT DESCRIBING THE ABOVE AND OTHER FINDINGS WAS PREPARED (AUTHOR - DR. JOE SPURGEON)

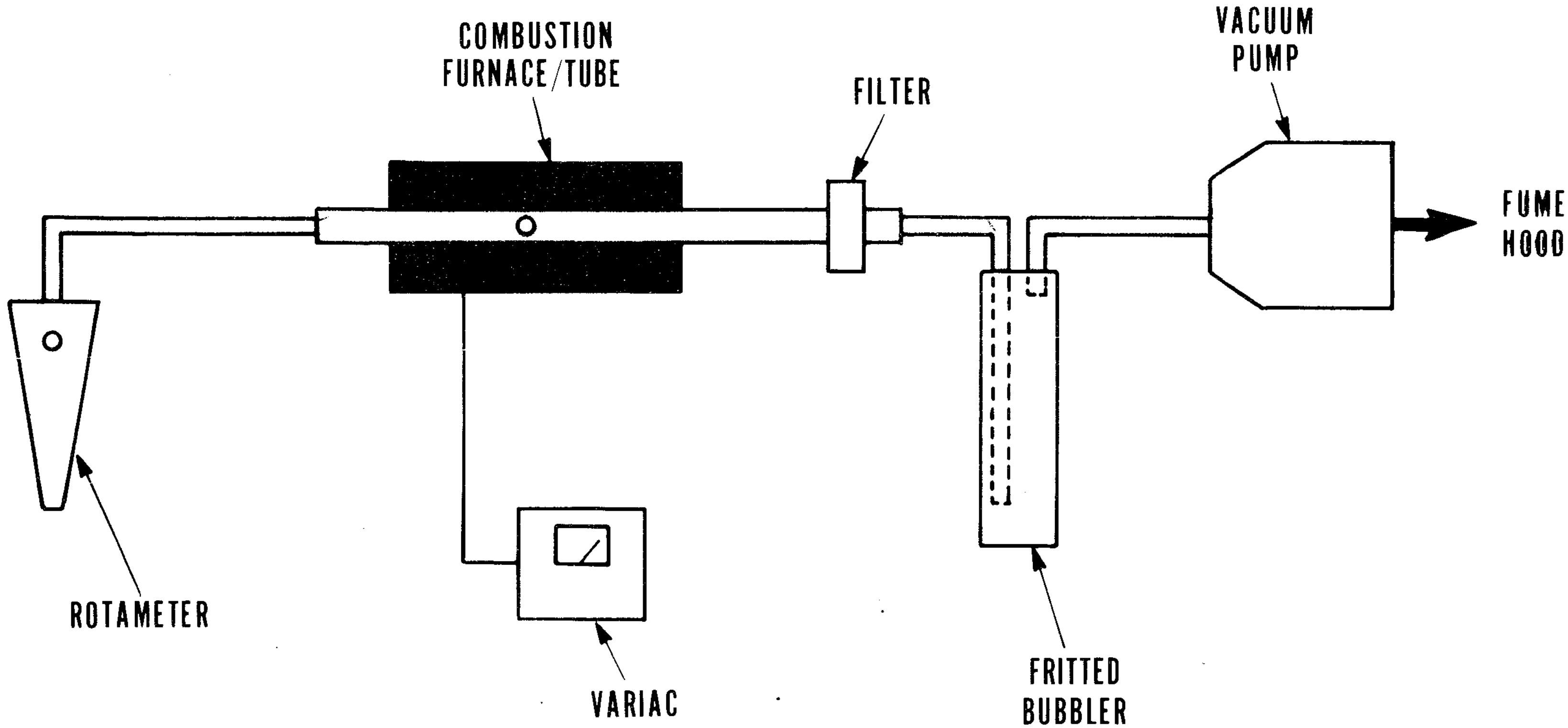
ADVANTAGES OF SYRINGE SAMPLING

1. BEST SAMPLE RECOVERY OF THE METHODS EVALUATED
2. RAPID SAMPLING TIME (APPROXIMATELY 10 SECONDS)
3. SMALL SAMPLE VOLUME (30 CC. = 0.006% OF THE NBS CHAMBER VOLUME)
4. CHEMICAL RESISTANT TEFLON PLUNGER AND HUB
5. SIMULTANEOUS MULTIPLE SYRINGE SAMPLING IS PRACTICAL
6. SIMPLE MANUAL OPERATION

SMOKE AND GAS TIME PROFILES FOR A PVC FABRIC (#81) TESTED IN THE NBS CHAMBER



SCHEMATIC DIAGRAM OF THE MICROCOMBUSTION TUBE ASSEMBLY



REPRODUCIBILITY OF HCL FOR A PVC FABRIC #81

NBS CHAMBER (SYRINGE SAMPLING)

TEST NO.	SAMPLE WEIGHT (g)	MAXIMUM CONCENTRATION (ppm)	HCl YIELD (mg/g)	THEORETICAL YIELD (%)
1	4.89	2740	408	69.9
2	5.05	2970	429	73.4
3	5.01	2710	395	67.7

AVERAGE YIELD = 411 mg/g

AVERAGE THEORETICAL YIELD = 70.3%

RELATIVE STANDARD DEVIATION = 4.1%

COMBUSTION TUBE FURNACE

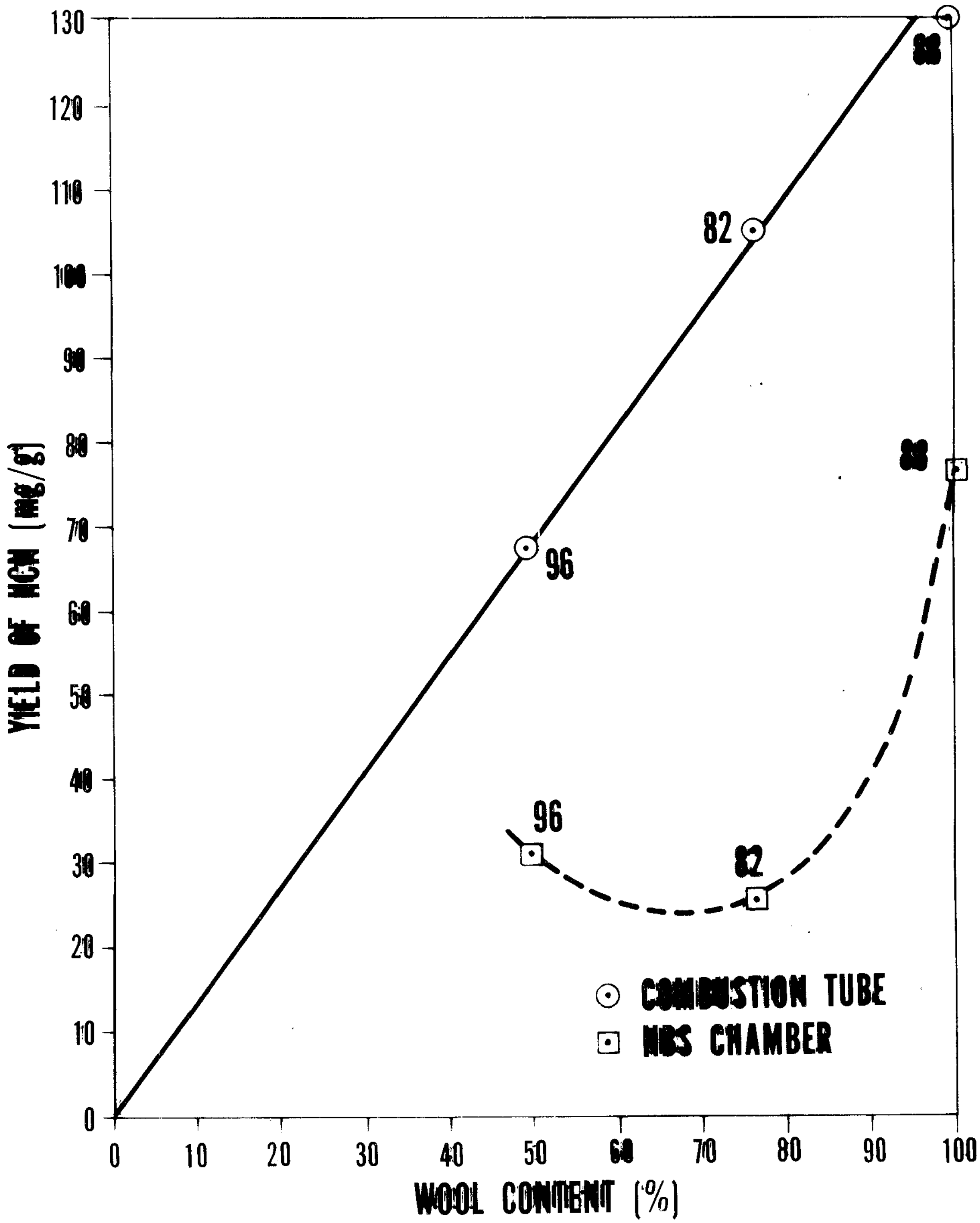
TEST NO.	SAMPLE WEIGHT (mg)	WEIGHT LOSS (mg)	HCl YIELD (mg/g)	THEORETICAL YIELD (%)
1	10.2	9.8	524	89.7
2	10.1	9.6	552	94.5
3	11.0	10.6	554	94.9

AVERAGE YIELD = 543 mg/g

AVERAGE THEORETICAL YIELD = 93.3%

RELATIVE STANDARD DEVIATION = 3.0%

RECOVERY OF HYDROGEN CYANIDE FROM WOOL/PVC FABRICS



CALCULATION OF A RELATIVE HAZARD INDEX (RHI)

FORMULA

$$RHI \quad \Sigma \frac{C_e}{C_i}$$

Where C_e = experimental gas concentration

C_i = brief exposure tolerance limit

ESTIMATED BRIEF EXPOSURE TOLERANCE LIMITS

TOXIC GAS	TOLERANCE LIMIT (PPM)
CO	5,000
HCN	200
HCl	50

SAMPLE CALCULATION

Suppose the following toxic gas concentrations were measured:

CO = 600 ppm, HCN = 600 ppm and HCl = 5 ppm

$$\therefore \; RHI \quad \frac{C_{CO}}{TL_{CO}} + \frac{C_{HCN}}{TL_{HCN}} + \frac{C_{HCL}}{TL_{HCL}}$$

$$\frac{600}{5000} + \frac{600}{200} + \frac{5}{50}$$

$$0.12 + 3.0 + 0.1$$

$$3.22$$

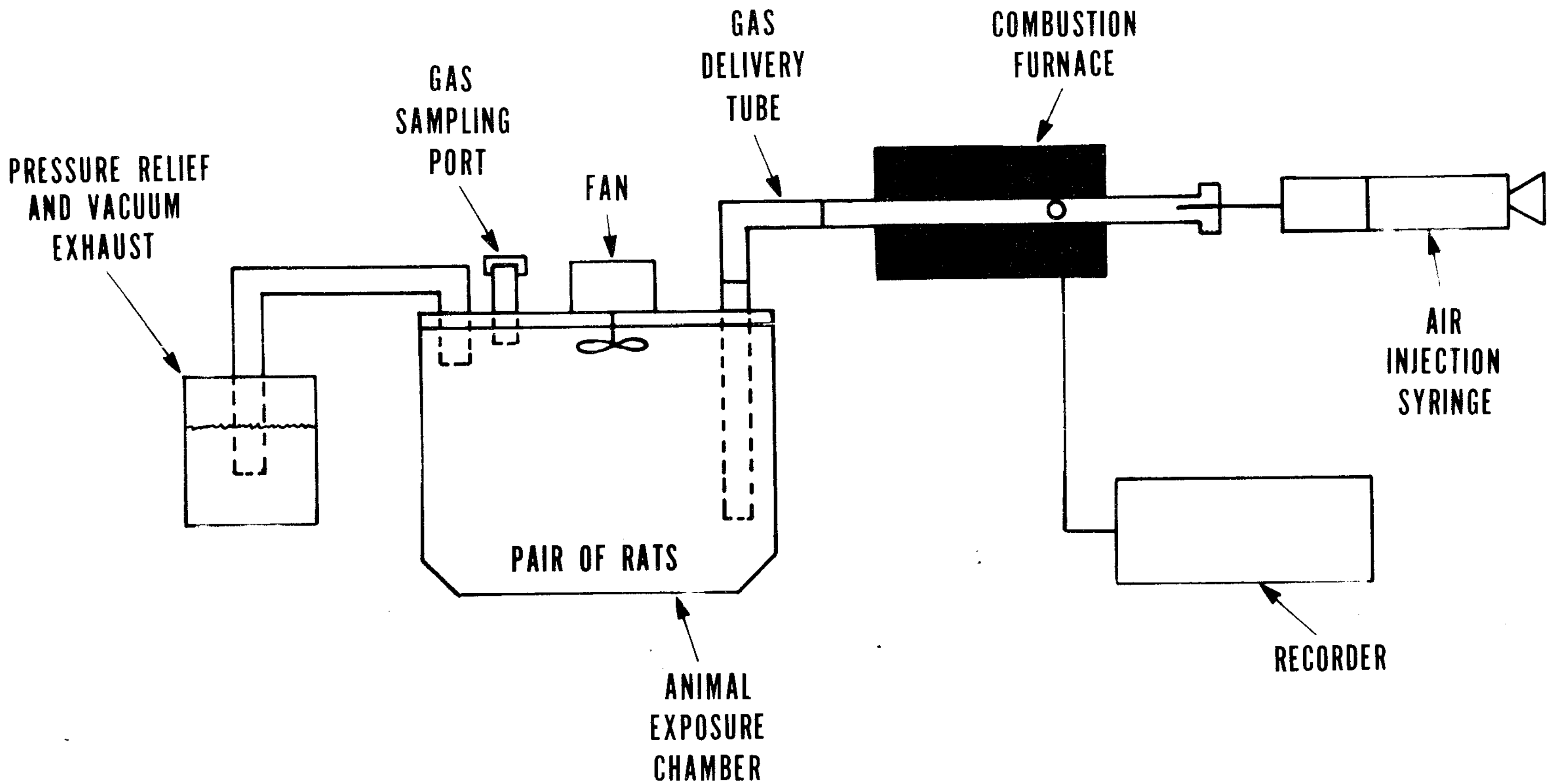
CLASS RANKING OF MATERIALS BASED ON A CALCULATED RELATIVE HAZARD INDEX

	NO.	COMPOSITION	CLASS RANKING COMBUSTION TUBE (10^{-3})	CLASS RANKING NBS SMOKE CHAMBER
FABRICS	81	PVC	200	44.7
	96	WOOL (49%)/PVC (51%)	97.6	15.6
	82	WOOL (76%)/PVC (24%)	62.4	9.73
	88	WOOL	1.81	0.28
	78	NOMEX	0.47	0.09
FOAMS	86	PVC	39.1	6.96
	143c	POLYESTER URETHANE	0.19	0.26
	79	POLYETHER URETHANE	0.09	0.10
	143a	POLYETHER URETHANE	0.08	0.13
	104	POLYESTER URETHANE	0.03	0.18
CARPETS	34	WOOL PILE/URETHANE PAD	0.71	0.44
	33	WOOL PILE	0.47	0.45
PANELS	67	PVC FACE/NOMEX CORE	77.3	15.3
	56	PVC ON ALUMINUM	48.2	60.2
	24	PVC CORE/FG FACES	13.0	14.5

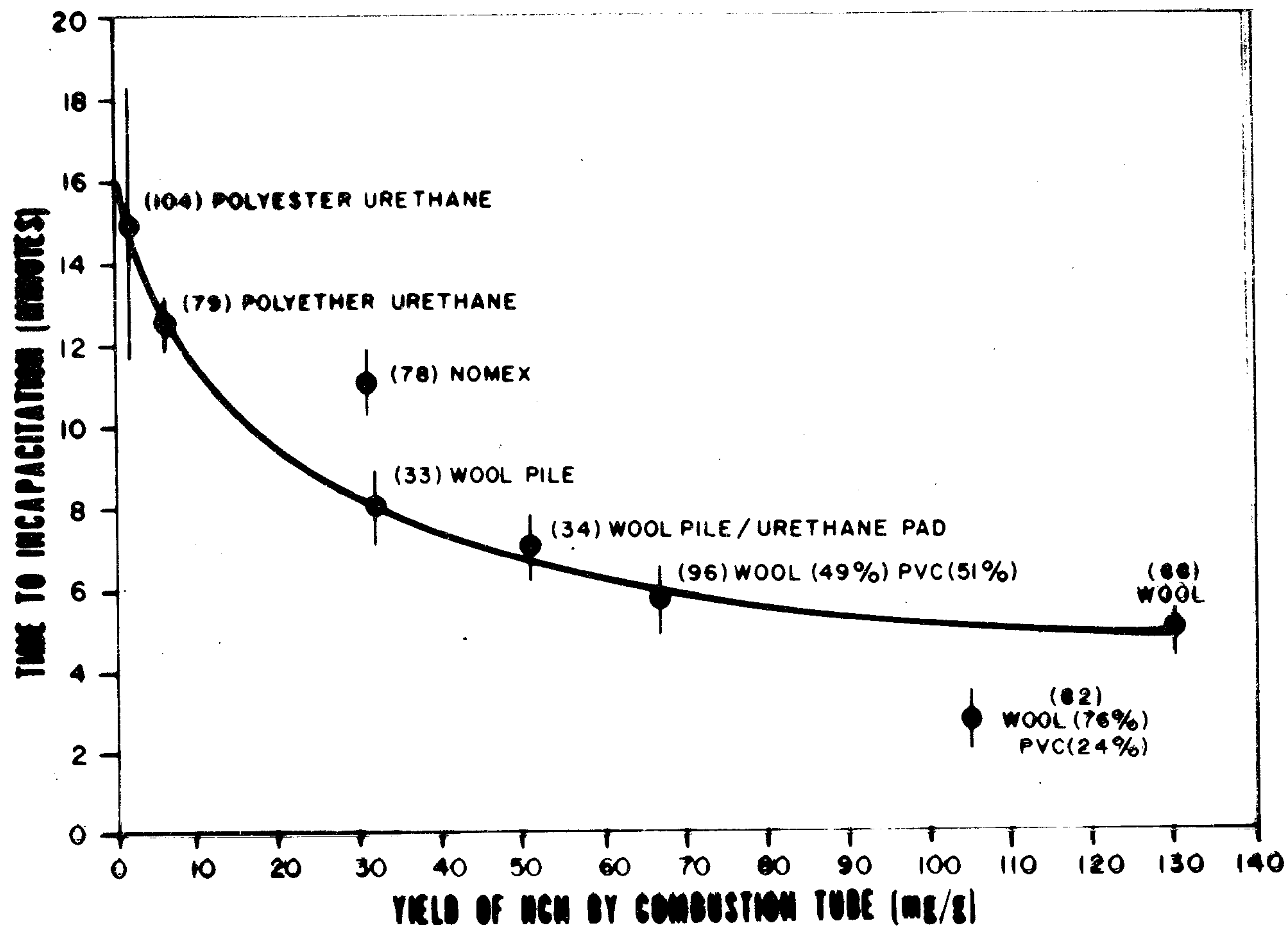
GENERAL RANKING OF MATERIALS BASED ON
A CALCULATED RELATIVE HAZARD INDEX

COMBUSTION TUBE		NBS SMOKE CHAMBER	
81	PVC'S (PANELS, FOAMS & FABRICS)	56	CONTAIN CHLORINE
96		81	
67		96	
82		67	
56		24	
86		82	
24		86	
88	WOOLS (CARPETS & FABRICS)	33	CONTAIN NITROGEN
34		34	
33		88	
78	NOMEX	143c	URETHANE FOAMS
143c (URETHANE FOAMS)		104	
79 (URETHANE FOAMS)		143a	
143a (URETHANE FOAMS)		79	
104 (URETHANE FOAMS)		78 (NOMEX)	

ANIMAL TEST APPARATUS



CORRELATION OF ANIMAL RESPONSE WITH YIELD OF HCN MEASURED BY THE COMBUSTION TUBE



MAJOR CONCLUSIONS

(1) SYRINGE SAMPLING IS THE MOST APPROPRIATE FOR SAMPLING COMBUSTION GASES FROM THE NBS CHAMBER (OF THESE METHODS EVALUATED).

(2) REPRODUCIBILITY OF THE MEASUREMENTS OF HCl AND CO ARE SLIGHTLY BETTER AND HCN SIGNIFICANTLY BETTER FOR THE COMBUSTION TUBE FURNACE THAN THE NBS CHAMBER. THIS PARAMETER IS MORE DEPENDENT UPON MATERIAL COMPOSITION THAN METHODOLOGY.

(3) IN THE COMBUSTION TUBE FURNACE, THE RECOVERY OF HCl AND HCN WAS DIRECTLY RELATED TO MATERIAL COMPOSITION. HOWEVER, THE RECOVERY OF THESE GASES WAS MUCH LOWER IN THE NBS CHAMBER, AND WAS INVERSELY PROPORTIONAL TO CONCENTRATION FOR HCl.

(4) THE RANKING OF FABRICS AND FOAMS BASED ON A COMPUTED RELATIVE HAZARD INDEX GENERALLY FOLLOWS THE SAME ORDER FOR THE COMBUSTION TUBE FURNACE AND NBS CHAMBER. THIS AGREEMENT DOES NOT EXIST FOR COMPOSITES (CARPETS AND PANELS).

(5) A COMPUTED RELATIVE HAZARD INDEX RANKED THE TOXICITY HAZARD OF INTERIOR MATERIALS - INCLUDING PANELS, FOAMS, FABRICS, AND CARPETS - IN THE FOLLOWING ORDER: PVC'S $>$ WOOLS $>$ URETHANE, OR NOMEX.

(6) THE RELATIVE TOXICITY OF HOMOGENEOUS INTERIOR MATERIALS BASED ON THE TIME TO INCAPACITATE RATS IS AS FOLLOWS: PVC $>$ WOOL $>$ NOMEX $>$ URETHANE. (THIS ORDER IS IDENTICAL TO THAT PREDICTED BY A RELATIVE HAZARD INDEX BASED ON COMBUSTION TUBE DATA).

(7) PRELIMINARY ANIMAL TESTS SUGGEST THAT THE TOXICITY OF BURNING NITROGEN - CONTAINING MATERIALS MAY BE RELATED TO THE YIELD OF HCN MEASURED FROM A COMBUSTION TUBE FURNACE.

(8) SOME PVC/WOOL BLENDED FABRICS MAY PRODUCE A SYNERGISTIC TOXIC EFFECT WHEN BURNED.

(9) DETERMINATION OF THE TIME TO INCAPACITATION OF ANIMALS EXPOSED TO THE BURNING PRODUCTS OF INTERIOR MATERIALS OFFERS A RELATIVELY QUICK, REPRODUCIBLE AND RELEVANT METHOD FOR ASSESSING THE HAZARD FROM TOXIC GASES.

(10) A PRELIMINARY ANALYSIS OF ANIMAL AND ANALYTICAL TEST DATA TAKEN INDEPENDENTLY INDICATES THAT A MEANINGFUL REGULATION CAN BE BASED ON AN ANALYTICAL APPROACH.

PRESENT EFFORTS

(1) THE 75 CABIN MATERIALS ARE FIRST BEING TESTED IN THE NBS CHAMBER AND THE SELECTED TOXIC GASES MEASURED WITH COLORIMETRIC TUBES. THIS DATA IS BEING USED TO:

(A) IDENTIFY THE GASES PRESENT IN ORDER TO REDUCE AND DICTATE THE NATURE OF SUBSEQUENT ACCURATE ANALYTICAL MEASUREMENTS, AND

(B) FURTHER ASSESS THE APPLICABILITY OF A RELATIVE HAZARD INDEX BASED ON COLORIMETRIC TUBE DATA FOR RANKING MATERIALS OF THE SAME CHEMICAL COMPOSITION OR CABIN USAGE.

(2) CONCURRENTLY, ACCURATE ANALYTICAL PROCEDURES ARE BEING DEVELOPED TO MEASURE THE SELECTED TOXIC GASES.

(3) ASSEMBLY, FAMILIARIZATION, CALIBRATION AND INITIAL TESTING OF NEW THERMOGRAVIMETRIC ANALYZER AND COMBUSTION TUBE FURNACE.

(4) HOPEFULLY BY JULY 1 WE WILL HAVE THE FOLLOWING INFORMATION FOR THE 75 CABIN MATERIALS:

(A) CONCENTRATION-TIME PROFILES IN THE NBS CHAMBER USING COLORIMETRIC TUBES (FLAMING EXPOSURE, ONE TEST/MATERIAL).

(B) CONCENTRATION-TIME PROFILES IN THE NBS CHAMBER USING ACCURATE ANALYTICAL PROCEDURES (FLAMING EXPOSURE, 3 TESTS/MATERIAL).

(C) YIELD OF THE SELECTED GASES MEASURED FROM THE COMBUSTION TUBE FURNACE ($600^{o}C$, 3 TESTS/MATERIAL).

(D) THERMOGRAVIMETRIC DATA (WEIGHT LOSS AND RATE OF WEIGHT LOSS VS TEMPERATURE, ONE TEST/MATERIAL).

NBS CHAMBER SMOKE AND GAS ANALYSIS

Test No. 43 Sample No. 34A Date 1/10/75

Sample Description Rug w/urethane backing

Thermal Exposure: Flaming ✓ Smoldering ____

Time (min)	% Trans.	Ds	CO	HCl	HCN	HF	H_2S	NO_x*	NH_3	HCHO	SO_2	TDI
0.5				0		0						
1.0			40		10		0	30	0	0	100	
1.5				28		0						
2.0			150		25			60		5	150	
2.5				>120		–						
3.0			400		30			80		20	160	
3.5				>120		–						
4.0			500		35		0	90	0	30	160	
4.5				>120		–						
5.0			500		45			100		30	175	
5.5				>120		–						
6.0			500		50			90		40	175	
6.5				>120		–						
7.0			700		50			100		50	180	0
7.5				>120		–						
8.0												
8.5												
9.0												
9.5												
10.0												

Initial Wt. 10.41 Wt. Loss 6.45 %Wt. Loss 62

Min. Trans. (%) .061 at 4.6 min. ____

Maximum Specific Optical Density, D_m 431

Time to Reach 90% D_m 3.4 min.

Clear Beam Reading (%) 88 Equiv. D_c 7.4

D_m (corr.) = D_m - D_c 424

Chemical Analysis:
Colorimetric Tube All gases
Ion Selective Electrode ____ LIRA ____

Remarks: * Last 6 color tubes saturated at one stroke!
96°F Flaming from start. Reduced flame at 2.3 to Small with flame out at 4. min.

RECOMMENDATIONS

TO SATISFY FLIGHT STANDARDS SERVICE REGULATORY PROPOSALS ON

(1) TOXIC GAS EMISSIONS

- (A) IMMEDIATE MINIMAL NEEDS
- (B) FUTURE COMPREHENSIVE NEEDS

(2) CABIN FIRE SAFETY

IMMEDIATE MINIMAL NEEDS FOR A TOXIC GAS EMISSIONS REGULATION

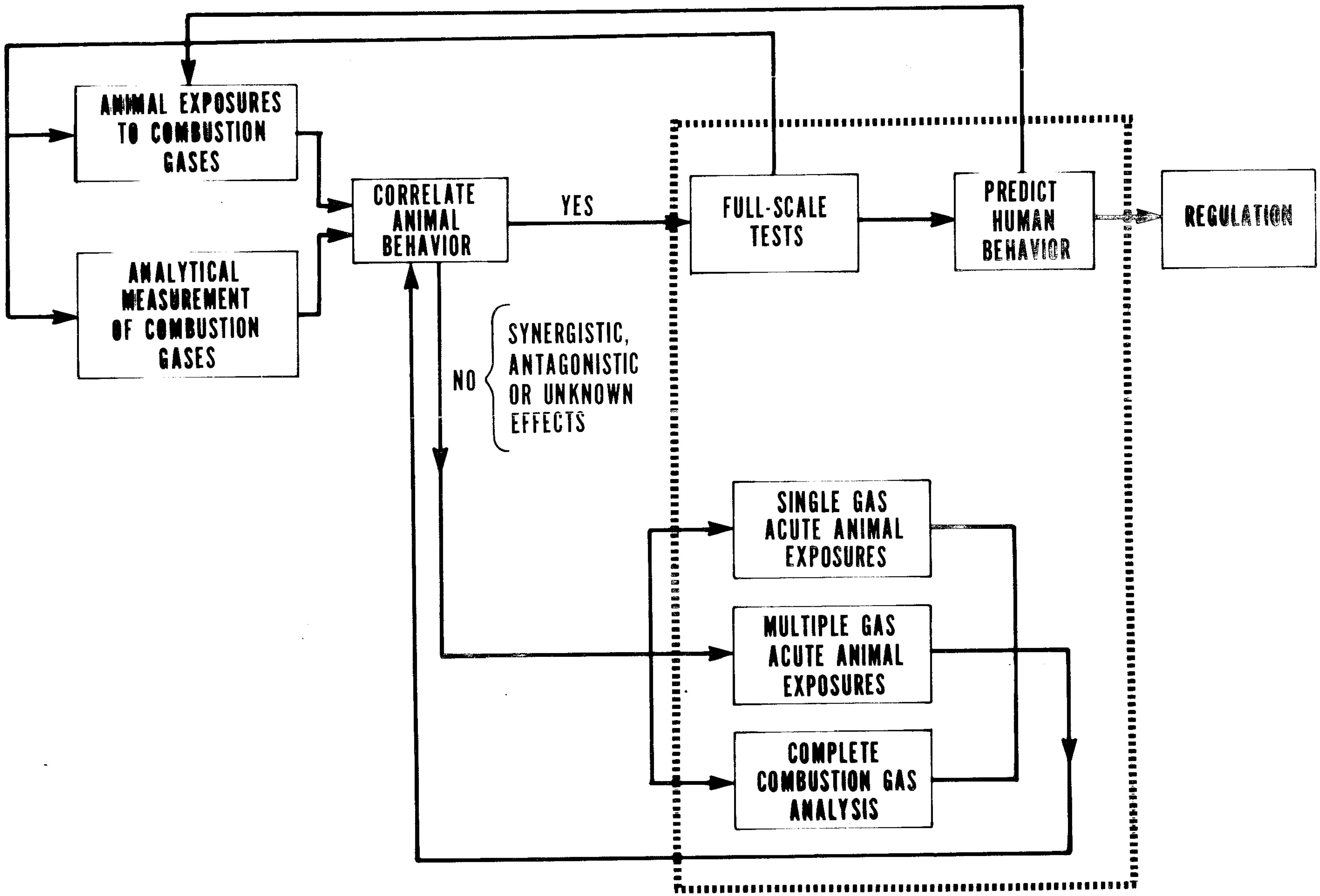
1. CAMI BE REQUESTED TO CONDUCT TESTS WITH ANIMALS EXPOSED TO THE COMBUSTION PRODUCTS OF THE 75 CABIN MATERIALS PRESENTLY BEING ANALYZED AT NAFEC.

2. THIS EFFORT SHOULD BE COORDINATED WITH NAFEC TO ASSURE A CONSISTENT APPROACH AND COMMON GOALS.

3. THIS EFFORT SHOULD INCLUDE BUT NOT BE LIMITED TO THE FOLLOWING:

   - MEASUREMENT OF THE TIMES TO INCAPACITATION AND DEATH.
   - TIME PROFILE MEASUREMENTS OF THE PREDOMINANT TOXIC GASES.
   - GROSS POST-MORTEM PATHOLOGICAL EXAMINATIONS.
   - POST-EXPOSURE MONITORING.

FUTURE COMPREHENSIVE NEEDS FOR A TOXIC GAS EMISSIONS REGULATION



THE POSSIBLE APPLICATION OF A FULL-SCALE CABIN FIRE TEST FACILITY TO REGULATORY NEEDS

- DETERMINE THE RELATIVE IMPORTANCE OF THE FLAMMABILITY, SMOKE AND TOXIC AND COMBUSTIBLE GAS EMISSIONS OF INTERIOR MATERIALS ON PASSENGER SURVIVABILITY.

- ASSESS THE IMPORTANCE OF MATERIAL LOCATION (e. g. , FLOOR, SIDEWALL, CEILING, ETC.) ON THE CABIN FIRE HAZARD; DERIVE AN "INVOLVEMENT FACTOR."

- DERIVE "RATIONAL" LIMITS FOR THE FIRE PERFORMANCE OF INTERIOR MATERIALS.

- APPLY FULL-SCALE FIRE TEST DATA TO THE REDESIGN OF PRESENT OR DEVELOPMENT OF NEW LABORATORY FIRE TEST METHODS TO ASSURE RELEVANCY TO A "REAL FIRE."

- EVALUATE PROPOSED MATHEMATICAL MODELS OR SCALING CRITERIA.

- EVALUATE THE UTILITY OF ALTERNATE FIRE CONTROL TECHNIQUES (e.g., COMPARTMENTATION, HARDENING, DETECTION, SUPPRESSANT AGENTS/SYSTEMS, ETC.).